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EFFICACY OF GROUND-APPLIED ULTRA-LOW–VOLUME MALATHION ON HONEY BEE SURVIVAL AND PRODUCTIVITY IN OPEN AND FOREST AREAS

PHILIP G. HESTER,[1] KENNETH R. SHAFFER,[1] NOOR S. TIETZE,[2] HE ZHONG[1] AND NORMAN L. GRIGGS, JR.[1]

ABSTRACT. A study was conducted to determine the efficacy of ground ultra-low–volume malathion sprays on honey bee (*Apis mellifera* L.) apiaries in open and forested areas downwind from the spray route. Impact on colonies 7.6, 15.2, 47.7, and 91.4 m downwind from sprays was assessed by recording individual bee mortality 12 and 36 h after treatment. In addition, hives were weighed before as well as during the study and cluster counts were conducted at each hive to determine colony strength before and after treatment. Spray drift was monitored by the use of caged mosquito (*Culex quinquefasciatus* Say) mortality and deposition on filter paper. During the study, significant bee mortality in the open area occurred on 2 occasions at 7.6 m (16.8 ± 4.3 bees, 11.8 ± 7.0 bees) and at 15.2 m (6.5 ± 1.7 bees, 5.3 ± 1.5 bees). Significant mortality in the forested area was observed only once and consisted of 2 bees at 7.6 m. In each case where bee mortality occurred, spray deposits on filter papers had exceeded 400 ng/cm^2. Although mortality of caged mosquitoes indicated that malathion drifted through the study areas, little correlation was apparent between mortality and spray deposition on filter paper.

KEY WORDS *Apis mellifera*, malathion, ground ultra-low–volume application

INTRODUCTION

A concern of Florida apiculturists is that the broadscale application of mosquito control insecticides adversely affects hive production. Some Florida apiculturists have reported bee kills resulting from application of mosquito adulticides that are part of routine public health spraying (personal communication with Florida mosquito control directors). Mosquito adulticides in the state are applied by either aircraft or truck and can cover large portions of the state, particularly along coastal communities.

Caron (1979) measured the effects of truck-based application of ultra-low–volume (ULV) malathion on caged bees and colonies in a Maryland community. Caged bee mortalities were significant at 15 m (68%) and 30 m (39%), with little kill at 60 m. Caron (1979) found that night applications had no affect on bee colonies, whereas day applications resulted in consistent losses. Aerial mosquito control in Hale County, Texas, using technical-grade malathion with spraying starting at dawn for a 2-h period resulted in noticeable bee kills when hives were not protected (Hill et al. 1971).

During the summer in Florida, warm nighttime temperatures of 24–31°C cause bees to aggregate outside the hive entrance where they attempt to cool the brood chamber by fanning their wings. These bees aggregating outside of the hive are more likely to be exposed to mosquito control applications, which thereby could possibly weaken the bee colonies and reduce honey production and pollination activities. This study was conducted on honey bee (*Apis mellifera* L.) colonies in open and forested areas to determine if ground ULV applications of malathion would affect the colonies.

MATERIALS AND METHODS

The study area was located within a secured portion of land controlled by St. Joe Paper Company, Bay County, Florida. Vegetation in the general area consisted of loblolly pine (*Pinus taeda* L.) and slash pine (*Pinus elliottii* var. *elliottii* Englem.) silviculture stands in various stages of growth. An open area was selected where bee hives were placed in the middle of a forest service road that ran through a field of young pines about 1.5 m high. The forested area consisted of mature pines with an understory of trees and shrubs. A control site was located at the edge of mature pines that bordered young pines.

Hives with frames were placed on pallets at open, forested, and control sites. Each treatment site had 4 hives placed at 7.6, 15.2, 45.7, and 91.4 m from the road for a total of 16 hives at each site. The hives were perpendicular to and on the northeast side of roads that ran in a southeast to northwest direction. This arrangement allowed ground truck spray treatments to drift toward the hives when winds were from the southwest, the prevailing nightly wind during the summer. Four hives that served as untreated controls were placed upwind approximately 1.2 km from the 2 spray sites.

On March 21, 1997, 1.36-kg packages of bees with queens (Millry Bee Company, Millry, AL) were placed in each hive. Each hive was supplemented with 1-liter jars of corn syrup to provide a readily available source of food for the worker bees to allow queens to produce brood. By mid-April the

[1] John A. Mulrennan, Sr. Arthropod Research Laboratory, Florida Agricultural and Mechanical University, 4000 Frankford Avenue, Panama City, FL 32405.

[2] Santa Clara County Vector Control District, 976 Lenzen Avenue, San Jose, CA 95126.

syrup supplement was removed because adequate natural food sources were available, including gall berry (*Ilex coriacea* Pursh), youpon (*I. vomitoria* Ait.), and Ogeechee tupelo (*Nyssa ogeche* Bartr.). As these species were declining another species of gall berry (*I. glabra* L.) became prevalent. In early June a sugar water supplement was added to the hives because the predominant flower was swamp titi (*Cyrilla racemiflora* L.), which may be toxic to the brood if used as the only source of food. As other plants flowered and titi waned, the sugar water supplement was removed for the remainder of the study. All honey bee colonies were continuously treated with Terramycin® (Dadant and Sons, High Springs, FL) and Apistan® (Dadant and Sons) during the study, a preventive measure against disease and parasites.

Insecticide applications were made by the South Walton Mosquito Control District using a Tuthill Corp. (M. and D. Pneumatics Division, Springfield, MO) blower powered by a 16.5-hp Briggs and Stratton (Milwaukee, WI) motor mounted on a pickup truck with the spray head angled at 30° above horizontal. The ULV spray head was equipped with a VecTec IHPLAT nozzle (VecTec Engineering Division, Rogers, MN). An Adapco Monitor and Modular Flow Control Pump (Adapco Inc., Sanford, FL) calibrated to deliver spray at a constant rate of 127 ml/min at 16 km/h (4.3 fluid oz/min at 10 mph) by automatically adjusting for vehicle speed. The material used was malathion (Fyfanon®) ULV concentrate 95% active ingredient (AI) (Cheminova, Wayne, NJ). Before each test, the droplet size generated by the machine was analyzed to determine if the droplets met the proper label requirements.

Malathion spray deposits were sampled at each hive distance by 2 filter papers (24-cm diameter) placed horizontally at ground level in front of the hives as described by Moore et al. (1993). Filter papers were collected after the spray had moved through the area and were placed into 150-ml Qorpak™ bottles (Fisher Scientific, Pittsburgh, PA) and immersed in 100 ml of petroleum ether. A sample was spiked at 20 ng/ml for each test site to determine percent recovery, and 2 filter papers were placed at the control site to serve as field blanks. Samples were stored in a freezer at −19°C until taken to the Department of Agriculture and Consumer Services Pesticide Laboratory (Tallahassee, FL) for analysis. A portion of each sample was removed and transferred to a gas chromatograph (GC) vial for analysis on a Perkin-Elmer Autosystem GC (Perkin-Elmer, Norwalk, CT) fitted with dual nitrogen–phosphorous detectors. Sample dilution or concentration was performed following the initial analysis. Data were collected and analyzed using the PE Nelson Turbochrom data system (Perkin-Elmer).

A 2nd method of monitoring the spray performance utilized caged adult mosquitoes (*Culex quinquefasciatus* Say) placed at each hive distance in the treatment areas as well as at the control bee site. Approximately 25 female mosquitoes between 2 and 8 days old were aspirated into steel cages (Rathburn et al. 1989). Mosquito cages were hung on stands at a height of 0.6 and 1.5 m above the ground at each station. Thirty minutes after exposure, the mosquitoes were anesthetized with CO_2 and transferred to clean cages. Mosquitoes were given access to 10% sucrose solution on cotton pads, and cages were covered with moist cotton to provide humid conditions before and after anesthetization. Mortality counts were made 12 h after treatment.

Short-term effects of the malathion treatments on the bees were assessed by a modified dead bee trap (Gary 1960). Dead bees were collected by placing 0.3-cm-mesh hardware cloth in front of the entrance of each hive. A 0.19-m^2 surface area in front of each hive was sampled with walls of the cloth 25 cm in height on the open sides to reduce the removal of bees beyond the sampled area. The dead bee trap was open at the top to allow easy removal of dead bees, which may have allowed some foraging by predators on the dead bees. Natural mortality rates were established by control hive counts as well as by counting dead bees for several days before treatment. Treatment effects were evaluated by counts 12 and 36 h after treatment.

The colony strength was assessed by the cluster count method (Nasr et al. 1990). This method estimated the percent of the frame tops that were covered with bees when the hives were opened, which gave a rapid estimate of colony changes with minimum disruption to the bees. Cluster counts were made before and after each treatment.

A final evaluation of the bee colonies was the weight gain that occurred from just before the initiation of treatments to after the final treatment. The hives were weighed at night when all bees were present. The weight that was obtained was then adjusted for actual bee production present by subtracting the weight of supers, frames, and lids.

Pre- and posttreatment mean mortality data and cluster counts were subjected to PROC GLM analysis of covariance (SAS 1982) to determine any significant difference in the pre- and posttreatment data. With respect to weight gain of hives, these treatment means were analyzed additionally by the Student–Newman–Keuls multiple range test.

The bee colonies were treated a total of 4 times over a period of 7 wk. Treatment times were between 2000 and 2030 h, which coincided with the cessation of bee flights.

RESULTS AND DISCUSSION

Wind speeds were low, ranging from 1.6 to 4.8 km/h (1 to 3 mph) and always from the road toward the hives. Temperatures ranged from 23.6 to 26.7°C at the time of treatment, whereas daytime temper-

Table 1. Mean number of dead bees per hive at different distances from spray route for pretreatment (Pre) and posttreatment (Post) counts during malathion ground ultra-low–volume tests.[1,2]

Area and distance (m)[3]	Test 1			Test 2			Test 3			Test 4		
		Post			Post			Post			Post	
	Pre	12 h	36 h	Pre	12 h	36 h	Pre	12 h	36 h	Pre	12 h	36 h
Open												
7.6	1.0	16.8s	2.0	0.3	1.0	0.8	0.2	0.0	0.3	0.5	11.8s	1.8
15.2	1.0	6.5s	1.5	0.3	0.8	0.5	0.4	0.0	0.3	0.1	5.3s	1.3
45.7	0.8	0.3	0.3	0.5	1.3	0.0	0.4	0.0	0.0	0.0	0.0	0.0
91.4	2.1	0.3	0.3	0.4	0.8	0.0	0.1	0.0	0.0	0.0	0.0	0.0
Forest												
7.6	3.0	1.5	0.3	0.9	0.0	0.8	0.5	1.5	0.8	0.4	2.0s	0.3
15.2	1.5	0.0	0.5	0.3	0.3	0.0	0.2	0.0	0.3	0.6	0.0	0.0
45.7	2.1	0.3	0.5	0.4	0.5	0.5	0.4	0.8	0.0	0.3	0.0	0.0
91.4	2.4	1.0	0.0	0.5	0.0	0.5	0.5	0.0	0.0	0.1	0.3	0.0
Check	1.1	0.8	0.8	0.5	0.0	0.3	0.0	0.0	0.3	0.0	0.0	0.3

[1] Data were subjected to PROC GLM analysis of covariance to determine if a significant difference ($P = 0.05$) existed between pre- and posttreatment counts. s, significant differences in means.
[2] Treatment dates June 16, July 1, July 21, and July 29, 1997.
[3] Four hives at each distance in open and forest areas.

atures approached 35°C during the afternoon. Humidity ranged between 86.2 and 98.4% during treatments. These conditions provided the desired scenario for bee aggregations at the hive entrances.

A significant number ($P < 0.05$) of dead bees were observed 12 h after treatment in the 1st and 4th tests in the open area (Table 1). Mean hive mortalities at 7.6 and 15.2 m from the spray route in test 1 were 16.8 ± 4.3 and 6.5 ± 1.7 bees, respectively. Mean hive mortalities at 7.6 and 15.2 m in test 4 were 11.8 ± 7.0 and 5.3 ± 1.5 bees, respectively. Treatment mortality of bees in the forest area was significant ($P < 0.05$) in test 4 only and consisted of a mean mortality of 2 bees per hive at 7.6 m at the 12-h posttreatment count. In each occurrence of significant bee mortality, the mean amount of malathion deposited exceeded 400 ng/cm^2 (Table 2).

The hive strength, as assessed by cluster counts of bees in the hives, did not indicate any significant differences ($P > 0.05$) in coverage between pre- and posttreatment counts in the open or forest area (Table 3). The mean area of the frames covered with bees within the hives ranged from 89 to 100%.

A wide variance in weight gain in hives occurred during this study (Table 4). Total weight gain of the aggregate of bees, wax, brood, and honey varied per hive from a loss of 2.84 kg to a gain of 29.71 kg. Mean weight gain for various locations of hives ranged from 5.08 to 11.17 kg. Weight gain between hive locations in the open, forest, and control areas

Table 2. Mean malathion (ng/cm^2) deposited on filter papers placed on the ground in front of bee hives during 4 ground ultra-low–volume sprays in 2 areas.

Area and distance (m)	Test number			
	1	2	3	4[1]
Open				
7.6	694[2]	99	283	593[2]
15.2	477[2]	44	132	631[2]
45.7	100	12	10	89
91.4	42	ND[3]	2	17
Forest				
7.6	93	140	65	422[2]
15.2	224	33	49	122
45.7	60	9	17	66
91.4	4	9	7	65

[1] The forest area in test 4 had been partially cleared by removing a row of trees on each side of the hive locations.
[2] Malathion concentrations at which significant bee mortality occurred.
[3] ND, not determined.

Table 3. Percent coverage of frames in bee cluster counts before and after treatment for malathion ground ultra-low–volume treatments.[1]

Distance (m) and area[2]	Pretreatment	Posttreatment			
		1	2	3	4
7.6 O	94	100	100	100	100
15.2 O	99	99	95	93	95
45.7 O	89	98	90	95	100
91.4 O	98	98	98	98	100
7.6 F	94	100	100	100	100
15.2 F	99	99	98	93	95
45.7 F	89	98	90	95	100
91.4 F	98	98	98	98	100
Check	94	98	98	98	98

[1] PROC GLM analysis of covariance did not indicate any significant difference between the means of the pre- and posttreatment samples ($P = 0.05$).
[2] Four hives at each distance in open (O) and forest (F) areas.

Table 4. Mean weight gains per hive treated 4 times with ground ultra-low–volume malathion applications.

	Open area		Forest area	
Distance (m)	Weight (kg)[1]	Range	Weight (kg)[1]	Range
7.6	5.36a	−2.84–10.21	7.37a	−2.49–14.74
15.2	5.08a	−0.79–9.75	5.90a	−0.45–9.30
45.7	10.95a	0.91–26.76	8.87a	7.94–12.81
91.2	10.49a	−0.11–26.31	6.72a	5.67–7.82
Check	11.17a	2.95–29.71	11.17a	2.95–29.71

[1] Different letters indicate a significant mean difference ($P < 0.05$) based on Student–Newman–Keuls multiple range tests.

did not show a significant difference when subjected to a Student–Newman–Keuls multiple range test.

Caged mosquito mortalities varied among tests in the open area but were fairly uniform at each distance during tests 1 and 3 (Fig. 1). Because of a wind shift to an undesirable angle at treatment time during test 2, less than 100% mortality occurred at the closest distance (7.6 m). Mosquito mortality in test 4 was similar to mortalities recorded for tests 1 and 3 out to cages set at 45.7 m from the spray route. However, only 4% mortality was recorded at 91.4 m. Malathion deposition on filter paper during this test at 91.4 m was 17 ng/cm^2 (Table 2), whereas in test 3 deposits of 10 and 2 ng/cm^2 killed 99 and 77% of the mosquitoes, respectively. Malathion deposits generally were indicative of mosquito mortality at the closest 2 distances; however, as indicated above, deposition did not mirror mortality at 45.7 and 91.4 m.

Mosquito mortality in the forested area (Fig. 2) during the 1st 2 tests was similar to that reported by Floore et al. (1991), where mortality in vegetated residential areas was 54% for *Cx. quinquefasciatus.* After the 2nd test, the paper company had removed a row of trees on each side of the hives, leaving only a strip of trees with understory directly in line with the hives. This created a funnel effect for the spray drift and mortality increased to a level comparable with that of the open area. The deposition of malathion in this area (Table 2) seemed to have no correlation with the resulting mosquito mortality.

If the malathion spray had been evenly deposited within the intended area of a 91.4-m swath, deposition on filter papers should have been at a concentration of approximately 608 ng/cm^2. During this study deposition of malathion on filter paper was much higher than in other studies that utilized

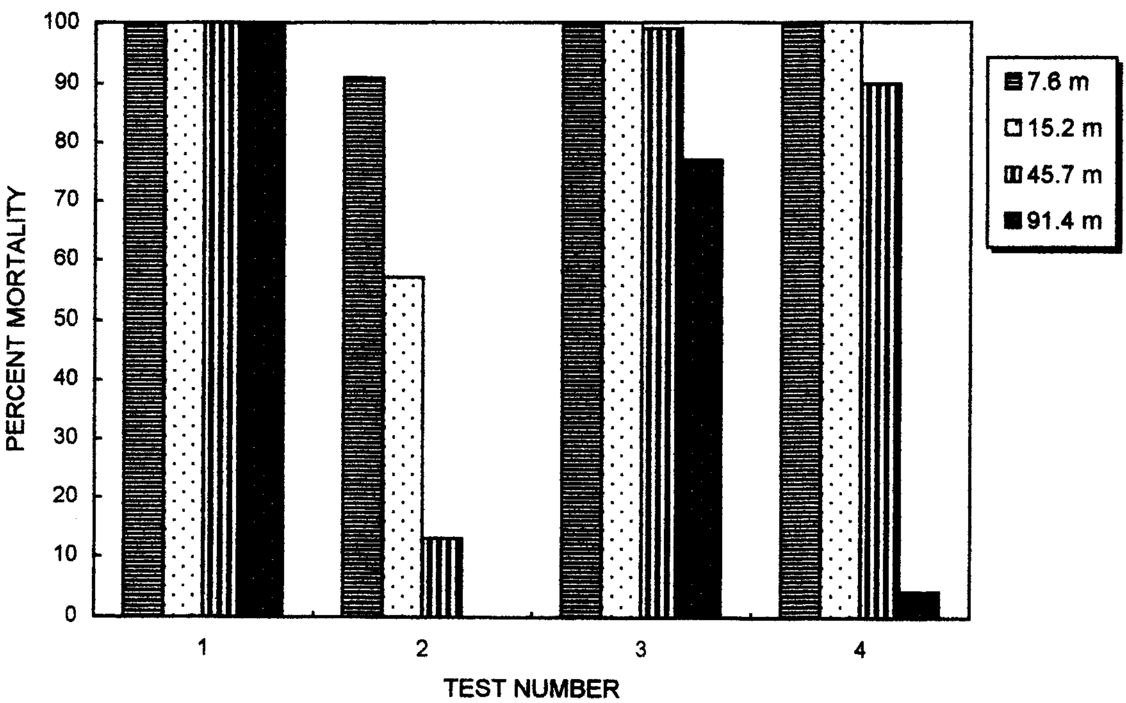

Fig. 1. Mortalities of caged *Culex quinquefasciatus* in the open area at various distances from the spray route during 4 ground ultra-low–volume malathion treatments.

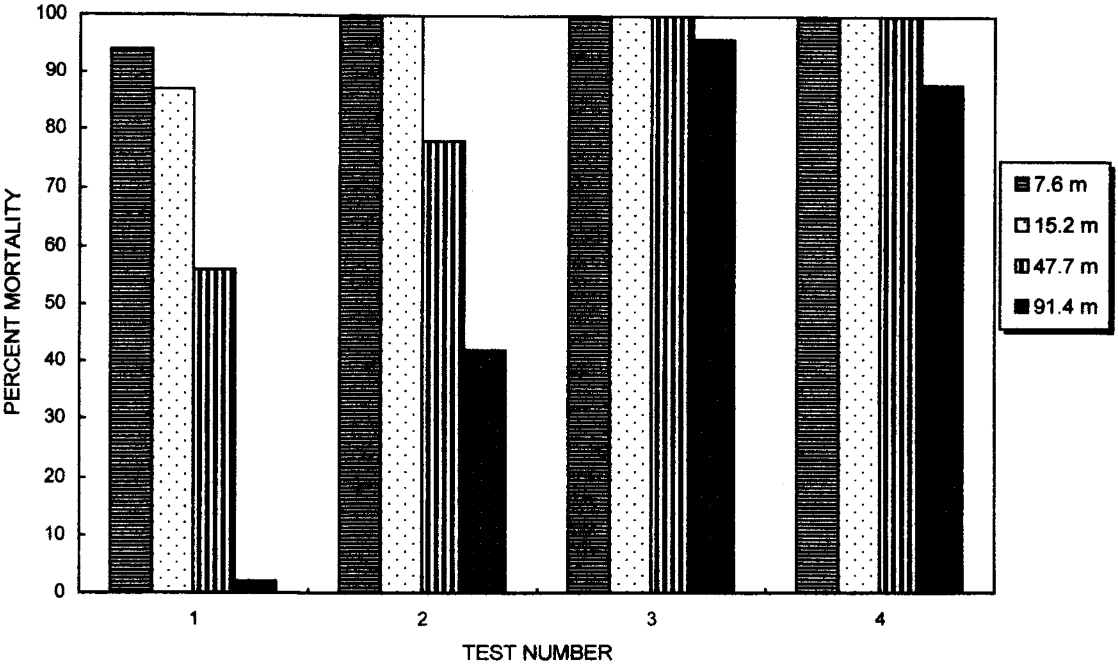

Fig. 2. Mortalities of caged *Culex quinquefasciatus* in the forest area at various distances from the spray route during 4 ground ultra-low–volume malathion treatments.

this method to monitor ULV deposition of mosquito sprays (Moore et al. 1993, Tietze et al. 1994). In 2 instances the mean deposition in the open area at specific sites exceeded the calculated uniform deposit and more nearly mirrored the results of Tietze et al. (1996). The latter study was in an area of residential structures with mature trees, whereas the former 2 studies were in open fields. Areas of various growth stages of pines within the general study area may have contributed to lower winds near the ground than in studies in open areas. Low winds would contribute to higher deposition rates because the aerosol spray would have more time to settle. Also, the 1.5-m pines that occurred in the open area on both sides of the road where hives were located might have formed a corridor for increased spray drift. These factors may have created a worst-case scenario for determining the effects of ULV spray on honey bees.

The present study produced results similar to those of Caron (1979) relative to bee mortality after ULV malathion mosquito treatments at night, even though application rates were higher and clusters of bees were observed on the outside of hives at the times of treatment. Although the highest bee mortality (16.8 bees per hive) occurred at 1 test locality, this value was within the range of acceptable natural mortality for bee hives (Tew 1998). Evaluations to determine the overall condition of the hives during the study did not indicate any adverse effects due to malathion treatment.

However, it would be advisable to place apiaries more than 15.2 m from roadways on which ground ULV mosquito applications normally occur. If this cannot be achieved, then a natural barrier of vegetation between the hives and the roadway would be desirable. More research is warranted to determine if other mosquito control adulticides applied by ground or aerial ULV spray at night could impact the apiculture industry.

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